Guidance Strategies for Service Module based aborts during ascent phase in Human Space Missions

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Abstract

The human space missions can be accomplished with different human rating aspects incorporated in the launch vehicle, of which a dedicated abort plan during the entire flight regime is inevitable. This paper presents the guidance schemes devised for the Service Module based aborts in the ascent phase of human rated launch vehicle.

The guidance strategies presented in this paper addresses various zones of abort which ensures that the crew module is landing safely in sea avoiding any possible impact on landmass and also to ensure that the impact range is such that it is at a favourable position for speedy crew recovery. The different abort zones, the logic for identifying the various zones of abort initiation and the various strategies employed in each abort zone is explained in this paper. Validation results show the abort requirements is met for dispersions in ascent launch vehicle performance and various dispersions in descent abort trajectories.

1. Introduction

The human space program is intended to launch human beings into space, stay in an orbit for around three days and bring them back safely to earth. The human rated launch vehicle HRLV is identified for the prestigious mission. A human-rated space system should accommodate the needs of the crew, effectively utilize their capabilities to accomplish the mission objectives, and protect the crew members from hazardous events. The concept of human-rating was primarily aimed at improving the reliability of launch vehicles for human use and increasing safety through the addition of escape/abort systems.

Thus, the most important prerequisite of any human space mission is to safeguard the human being and return them back to earth safely in the event of any unforeseen mishap happening during the entire spaceflight from lift-off till end of mission [1],[2]. This calls for a dedicated abort plan which is given in fig 1

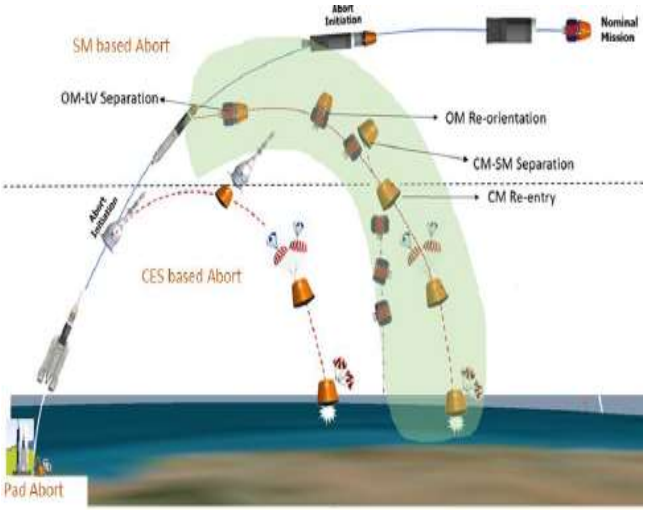

Fig 1 Abort Strategies during ascent phase of HRLV

During the ascent phase of manned mission, there are two modes of abort, (1) Crew escape system based during the atmospheric phase, (2) Abort using the propulsion system available in the service module (Orbital Module comprises of crew module and service module). This paper

deals with strategies during service module-based aborts

The requirements during this abort regime are:

- The deceleration levels experienced by the crew members during the abort flight should be within the acceptable g-levels. This is achieved by designing an ascent trajectory meeting this requirement.
- Sufficient separation gap with launch vehicle and Orbital Module has to be built after abort initiation so that any possibility of re-contact shall be avoided.
- Orbital Module shall be allowed to acquire a minimum altitude of around 100km (to perform re-orientation maneuver in upper atmosphere) after abort initiation.
- Since the crew module is designed for water landing, any impact possibility on landmass has to be avoided. Abort maneuvers shall ensuring in landing of Crew Module at safe zones in sea away from landmass.
- Abort guidance should also ensure that for high velocity regimes of the LV, the crew module impact has to be contained in safe waters near landmass for easy and speedy crew recovery process.
- When the vehicle reaches near orbital velocity, the vehicle should be maneuvered to reach an intermediate orbit for safe recovery

One of the challenges is due to the limitations in payload capability of ascent vehicle, there are regimes during the ascent flight during which the instantaneous impact of the vehicle is on land masses. In these regimes, human recovery can be possible only with the help of some intentional propulsive maneuvers.

Guidance for abort mission should be simpler and ensure that the black zones are avoided with planned maneuvers. In Apollo mission, five zones of abort [3]. Fixed attitude steering is done for simplicity. Orion uses numerical algorithm for its four abort zones [4]. Soyuz spacecraft had two abort modes that could be used between the launch escape system's ejection and orbit.

2. Zones of Abort

Depending on the different scenarios discussed above, the entire Service Module based aborts can be divided into four different abort zones:

- **Zone 1** where without any intentional maneuver, the crew module impact can be within safe waters.
- **Zone 2** where there is possibility of landmass impact, through active maneuvers using service module propulsion, the landmass impact has to be avoided.
- **Zone 3** which is the near orbital abort regime, where even for a small change in velocity of the launch vehicle, the impact will be far away from the landmass. For this zone, the crew module impact has to be brought back closer to the landmass.
- **Zone 4** When the LV is very near to orbital speed, abort to an intermediate orbit with minimum stable perigee.

3. Identification of Zone of Abort

The abort instance can occur anywhere within the timestamp of events (after Crew Escape System separation) of the ascent launch vehicle and the trajectory of the Orbital Module is decided by the flight conditions at the time of abort. The guidance algorithm has to identify the zone of abort initiation at first and then generate the abort trajectory accordingly. Sensitivities of different trajectory parameters were studied for precisely identifying the zone of abort initiation and instantaneous vacuum impact point and current perigee was identified to be giving acceptable results for all ascent Launch Vehicle performance.

Once an abort is initiated, the guidance algorithm

computes the Instantaneous Impact Point (IIP) online. If the velocity at abort initiation is less than a predefined value, abort zone is identified based on IIP. Otherwise, the zones are identified based on current perigee at abort initiation.

IIP is computed from the current position and velocity components in Earth Centered Inertial (ECI) frame and the current vehicle longitude at abort initiation are taken as inputs from navigation. The abort trajectory is assumed as a Keplerian trajectory as shown in Fig 2. IIP is then computed analytically from the fundamental orbit equations and mathematical relations.

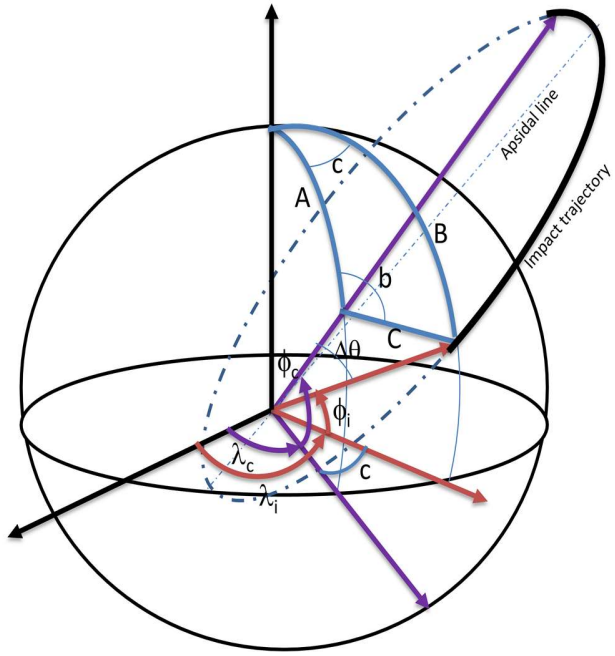

Fig 2 Instantaneous Impact Point

If λ_c and $\emptyset_c$ denotes the current vehicle longitude and latitude at point of abort initiation, t_{fall} is the time of fall, ω is the earth rotation rate, the geodetic impact longitude λ_i and geodetic impact latitude $\emptyset_i$ is given as

$$\lambda_i = \lambda_c + c - (t_{fall} \times \omega) \quad (1)$$

$$\emptyset_i = \frac{\pi}{2} - B \quad (2)$$

where

$$t_{fall} = \sqrt{\frac{a^3}{\mu}}[(E_i - E_c) - e \times sin(E_i - E_c)] \quad (3)$$

$$c = \sin^{-1}\left(\frac{\sin(A_{ZI})\sin(\theta_i - \theta_c)}{sinB}\right) \quad (4)$$

$$B = \cos^{-1}(sin(\emptyset_c)\cos(\theta_i - \theta_c) + \cos(\emptyset_c) \sin(\theta_i - \theta_c)\cos(A_{ZI})) \quad (5)$$

Here a is the semi major axis,
e is the eccentricity of the orbit,
E_c and E_i are the current and impact eccentric anomaly,
θ_c and θ_i are the current and impact true anomaly,
A_{ZI} is the velocity azimuth

The zone of abort is identified based on the instantaneous impact longitude computed from the trajectory parameters at the point of abort initiation.

4. Guidance Strategies for each Abort Zones

The guidance strategy for each above identified zones are explained in the flowchart given in Fig3. During all zones, orbital module is maneuvered along the velocity vector in the forward direction for a fixed time period (collision avoidance burn) to take it safely away from the ascent launch vehicle.

Zone 1 is categorized as region wherever safe impact in water can be ensured without any intentional maneuvers. No planned maneuver for impact containment is done.

For Zone 2, the instantaneous impact point of the crew module is on the landmass without any planned abort maneuver. So in order to avoid the impact on the landmass, the Orbital Module needs to be maneuvered by either reducing its velocity (retro burns) or increasing its velocity

(prograde burns). The retrograde firing strategy is being used during the initial portion of landmass impact zone which will pull back the Crew Module so that the actual impact will be before the landmass. In the remaining period of the landmass crossover, a prograde firing is employed which will push the crew module impact point beyond the landmass.

For Zone 3, since the instantaneous impact will be within safe waters but with very large impact range which is not at a favorable position for recovery, using retro burn maneuvers the impact is contained near to landmass. In such case also the initial collision avoidance burn is done.

For both Zone 2 and 3, an optimal steering profile generated to maximize range covered is stored as a look-up table onboard and the thrust cut-off is issued based on either accumulated velocity-based range to be travelled or upon reaching about 110 altitude to ensure safe separation of service module. A lookup table of range to go v/s Deltav for thrust cut-off (fixed through simulations) is stored onboard.

The range to be travelled in kilometers is given as:

$$R = 111 * \frac{180}{\pi} \sqrt{(\lambda_R - \lambda_i)^2 + (\phi_R - \phi_i)^2}$$

Where

λ_R and ϕ_R are the longitude and latitude for the target splashdown point

λ_i and ϕ_i are the analytically computed instantaneous impact longitude and latitude at the point of abort initiation.

For all the above abort zones, once the planned maneuvers are over, service module will be oriented to desired attitude for safe separation from Orbital Module. After Service Module – Crew Module separation, Crew Module will be again re-oriented to desired atmospheric entry conditions. Re-orientation guidance is devised appropriately for both the cases. During the re-entry, guidance will be commanding bank zero (full lift) trajectory till parachute deployment.

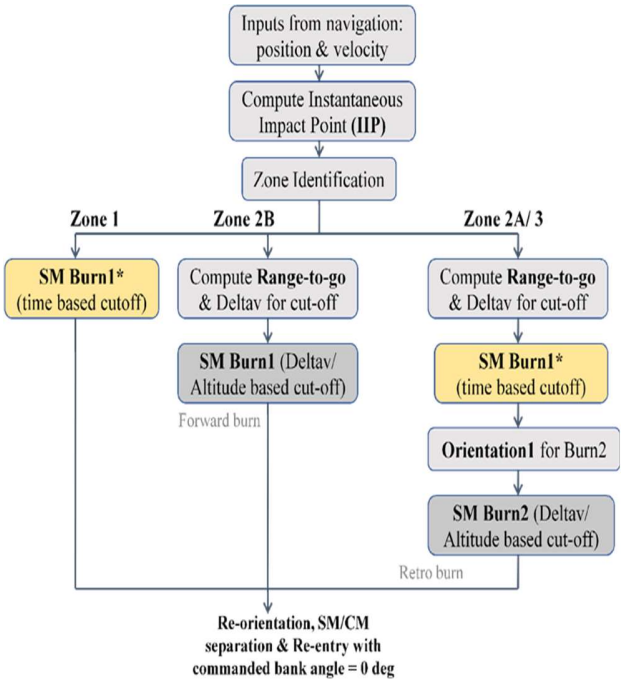
Inputs from navigation: position & velocity
Compute Instantaneous Impact Point (IIP)
Zone Identification
Zone 1
Zone 2B
Zone 2A/ 3
SM Burn1* (time based cutoff)
Compute Range-to-go & Deltav for cut-off
Compute Range-to-go & Deltav for cut-off
SM Burn1 (Deltav/ Altitude based cut-off)
Forward burn
SM Burn1* (time based cutoff)
Orientation1 for Burn2
SM Burn2 (Deltav/ Altitude based cut-off)
Retro burn
Re-orientation, SM/CM separation & Re-entry with commanded bank angle = 0 deg

Fig 3 Guidance algorithm flow for different abort zones

For Zone 4, the vehicle will be very close to orbital velocity and planned splashdown to a favorable target location in sea meeting range requirements will be difficult. In such cases, the Orbital Module will be steered in a fixed attitude with available Service Module propulsion such that the vehicle will be place in an orbit with minimum stable perigee. The crew will be recovered at the favorable location in Indian waters.

5. Results and Validation

Guidance strategy during SM based aborts is developed for various abort zones. The design is validated in a 6D simulation setup. The descent abort trajectory is simulated for all points from the ascent launch vehicle trajectory from Crew escape System separation till orbit injection. The g-levels experienced by the crew is found to be within the tolerable limits for all these conditions of Service Module based aborts as shown in Fig4. It is seen that the maximum deceleration level will be experienced by the crew when the

abort is initiated from the peak altitude point in the ascent trajectory and is less than 20g, well within the allowable physiological limits.

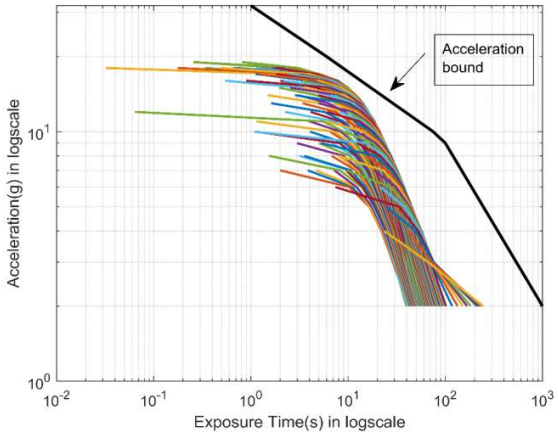

Fig 4 Deceleration levels experienced by crew

The guidance design considers a Service Module configuration of five LAM engines and sixteen RCS thrusters operated in off modulation having a thrust capability of approx 3KN.

The scheme is validated for prescribed dispersions in thrust and aerodynamic parameters during decent. In addition to this ascent vehicle dispersions are also considered A minimum clearance of around 100 km is ensured from the nearest landmass point for nominal and off nominal dispersion cases (Zone 2).

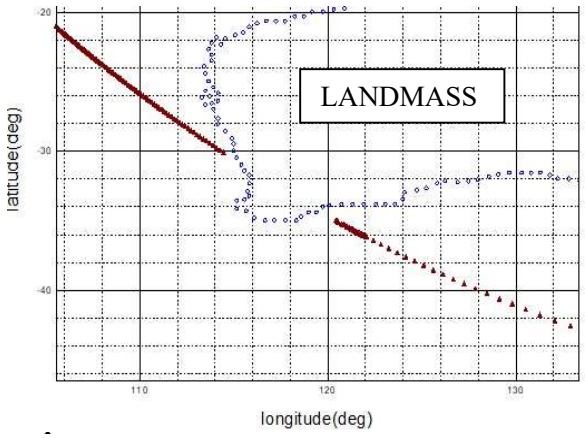

Fig 5 Impact points in Zone 2 after abort maneuver

The impact for near orbital aborts was also contained to the mission specified longitude using retro firing.

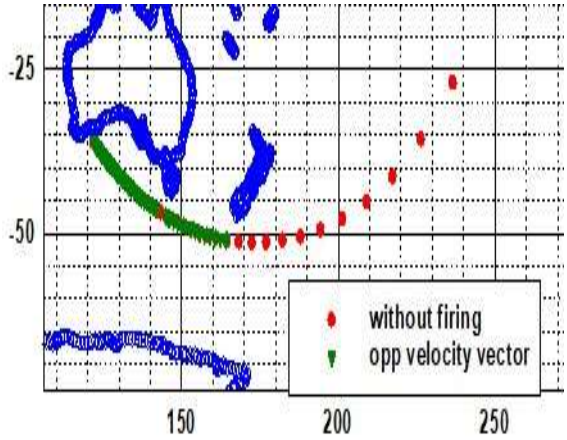

Fig 6 Impact point containment in Zone 3 with abort maneuver

6. Conclusion

The guidance strategies for safe recovery of crew during aborts during mission abort during ascent phase is developed and validated. For existing propulsion capabilities, the safe recovery of crew is ensured for dispersions in ascent Launch Vehicle performance and dispersions in descent abort trajectories.

7. References

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